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Semiannual Technical Summary

Graphics

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

GRAPHICS

SEMIANNUAL TECHNICAL SUMMARY REPORT
TO THE
ADVANCED RESEARCH PROJECTS AGENCY

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ABSTRACT

Efforts in the Graphics Program have continued to concentrate on the development of the Graphical Service System and VITAL, a compiler-compiler. The latter program is now operational. Development of a debugging system which utilizes graphics as a central communications medium has been initiated. In an effort to improve the methods of generating points, lines, and general conic sections in display systems, a simple waveform generator has been designed, based on homogeneous coordinate mathematics. The hardware problems in the implementation of this design are being investigated. A three-dimensional ultrasonic position-sensing device has been installed in TX-2 and initial evaluation is under way.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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GRAPHICS

I. GRAPHICAL SERVICE SYSTEM

Various programs for the Graphical Service System have been consolidated, the available matrix functions have been expanded, and display routines have been improved. The Wand has been connected to the computer and programs for its operation have been included in the APEX executive. Several experimental programs have been created to gain experience in the problems of interfacing with APEX. In addition, these have provided a test bed for various ideas about graphical control languages, using the light pen and various kinds of displayed light buttons. Additional work has been done on specifications for languages in which a user will describe the form of his control functions and the resulting actions upon a display.

Work in the next reporting period will be concentrated on assembling a complete first version of Graphical Service System. Limitations in its capabilities imposed either by the APEX executive or by gaps in our present knowledge will be tolerated in the interests of providing a working system for experimentation as rapidly as possible.

II. VITAL

The TX-2 compiler-compiler, VITAL, is now operational and has been used to construct compilers for two programming languages. Current efforts involve improving the user interface and extending the set of primitive operations. Several applications of VITAL to the graphics projects are under consideration.

III. GRAPHICAL DEBUGGING

A debugging system which employs graphics as its central communications medium is presently under development. The nature of the project requires parallel hardware engineering and software design. Presently, hardware has been supplied which performs the following tasks:

(a) Trap on reference to marked instructions.

(b) Trap on reference to marked data.

(c) Trap on all instructions.

(d) Suppress trapping when time-sharing executive is running.

(e) Report causes of traps.

Hardware is under construction to:

(a) Trap on all skip and jump instructions.

(b) Trap on arithmetic overflow.

(c) Supply the address of the instruction being performed when the trap was caused.

The software design is being carried out in two stages. The first is nongraphical and forms a base for the graphical portion. This stage is presently complete and adds to the standard symbolic debugging technique's two important facilities which have not been used before. They are:

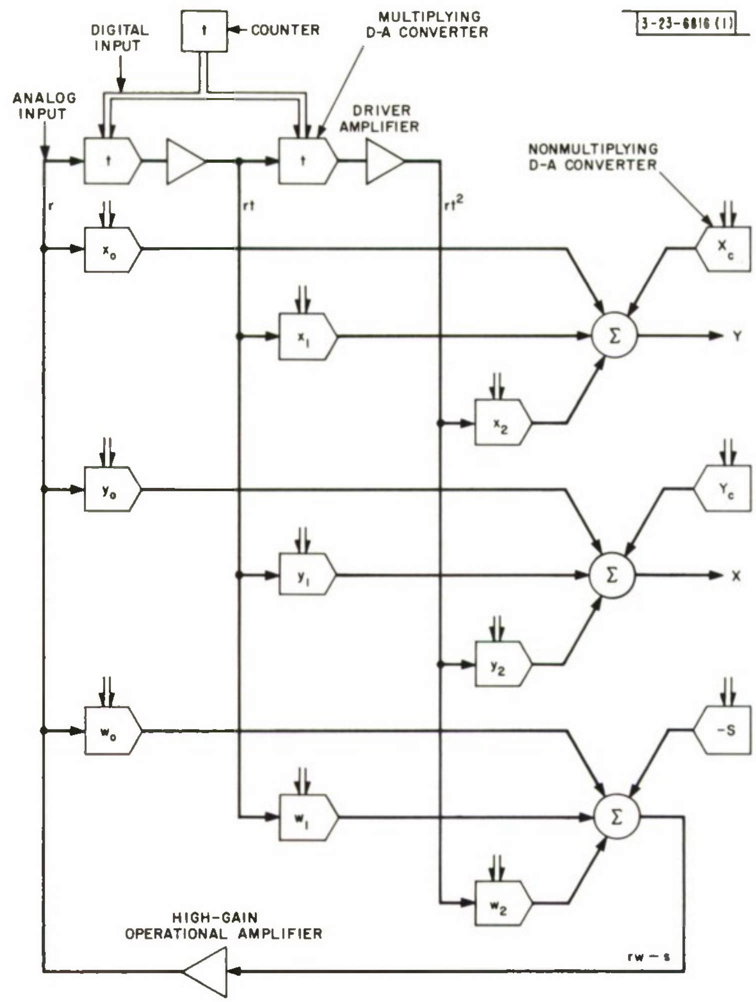


Fig. 1. Conic display generator.

(a) The symbolic ability to place program interrupts based upon data reference conditions as well as program flow without altering the state of the user's data or programs.

(b) The symbolic publication and analysis of user errors which involve illegal use of the time-sharing system. Such uses are memory protection violations, reference to information in nonauthorized modes, performance of instructions privileged to the executive only, and performance of instructions which can never terminate.

The second stage of software design centers around the production of flow maps from run-time address information. The display of such flow maps will permit graphical communication with the program via a light pen or the Wand for the purposes of editing, placing program interrupts, and conditioning flow-map augmentation and layout. In addition, it will permit the publication of quantities of program state information too bulky to be typed. Work on this stage of the software development was started early in May.

IV. CONIC DISPLAY GENERATOR USING MULTIPLYING DIGITAL-ANALOG CONVERTERS

A simple waveform generator for display systems has been designed on the basis of homogeneous coordinate mathematics. This generator will draw points, lines, and general conic sections. The fundamental waveform used is the parabola. Circles, ellipses, and hyperbolas are merely perspective transformations of the basic parabola which is represented by the parametric vector $\bar{t} = [t^2, t, 1]$. If H is a 3×3 matrix (the homogeneous transformation), then $\bar{p} = \bar{t}H$ is the position vector $\bar{p}[x, y, w]$ of some general conic. In order to display this curve, it is required that we now divide by the homogeneous scale factor w. Thus: $X = x/w$, $Y = y/w$ and X and Y can be applied to the deflection amplifiers of an oscilloscope. Since the divisions and multiplications required for this operation are generally expensive to implement, an unconventional hardware approach is required to make this method attractive.

The design of the homogeneous conic generator is based upon the assumption that a multiplying decoder can be built economically to produce an output voltage proportional to the product of a 10-bit digital number and a positive reference level. It must maintain 0.1-percent accuracy up to about 100 kcps. Since the requirement is only for two-quadrant multiplication (nonnegative reference voltage), the decoder design is fairly standard and by using micrologic flip-flop registers, the whole multiplying decoder package may be inexpensive. The design of a conic generator is shown in Fig. 1.

The equations describing its operation are:

$$r = S/w \qquad X = S\frac{x}{w} + X_c \qquad x = x_0 + tx_1 + t^2x_2$$

$$Y = S\frac{y}{w} + Y_c \qquad y = y_0 + ty_1 + t^2y_2$$

$$w = w_0 + tw_1 + t^2w_2$$

The system shown in the schematic has the following characteristics:

(a) The X_c, Y_c, S registers may be simple decoders (constant reference voltage). They are set for a whole subpicture in order to translate and scale it. (They may be eliminated if these features are not required.)

(b) The nine decoders ($x_0, x_1, x_2, y_0, y_1, y_2, w_0, w_1, w_2$) are set for each curve and only the t decoders driven by the counter change during the construction of a curve. The ramp and parabola outputs should be smoothed and amplified in order to drive the multiplying inputs.

(c) The feedback amplifier is an operational amplifier which will maintain r so that $rw - S = 0$. Thus $r = S/w$ and the division by w is accomplished.

(d) For a simple line, only (x_0, y_0) and (x_1, y_1) need be specified; x_2, y_2, w_2, and w_1 should be cleared and w_0 set to one.

(e) The count t should go from 0 to 2^n, where n is specified for each curve.

(f) If the velocity

$$[(\frac{\partial X}{\partial t})^2 + (\frac{\partial Y}{\partial t})^2]^{1/2}$$

can be calculated approximately from the output signals, a feedback loop can be set up to vary the counting rate of t in order to maintain constant velocity. This requires the differentiation of X and Y and the approximate squaring of these signals. (The square root itself is not necessary for the feedback loop.) Keeping a constant velocity has the advantage that the frequencies within the system are maintained at their limit, and the intensity of the curve remains constant. Still, it would probably be necessary to allow different values of n for the counter limit, since the dynamic range of speeds could not be too large.

Experiments have begun on the hardware design of the basic decoder and tests are being run on a simple closed loop such as required in the generation of t^2 in the final system.

V. THREE-DIMENSIONAL WAND

An ultrasonic position sensing device has been designed and installed on the TX-2 computer. It will allow the computer to determine periodically the x, y, and z coordinates of the tip of a pen-sized wand. The device can replace the light pen and Rand Tablet for two-dimensional work, and extend the usefulness of such devices by virtue of the extra dimension available. In order to replace the pointing function of the light pen, a comparator is required similar to the one currently installed on the TX-2 scopes. This allows the x, y coordinates of the Wand to be compared with scope beam position as each curve and vector is drawn and to cause an interrupt on coincidence.

The specifications of the device as it exists on the TX-2 are:

Accuracy	0.2 in.		
Working space	$4 \times 4 \times 4$ ft		
Resolution	0.1 in. – (9 bits/axis)		
Sampling rate	$\leqslant 30$ cps		
Wand velocity	< 6 in./sec for full accuracy		
Computer time	Processing	14 instructions	
	Present I-O	28 instructions	
		42 instructions = 130 μsec every 33 msec or 0.4% cost	

The technique currently being implemented uses four ultrasonic transducers and one ultrasonic receiver. Each transducer is pulsed periodically to produce a 20-μsec burst of sound, bandpass-limited between 20 and 100 kcps. This burst is heard by the receiver microphone after a time delay proportional to the distance between the two devices. The receiver amplifier is tuned for 50 kcps and thus rejects most room noises. Its output is clipped so that it outputs a pulse when the signal is received. This pulse is used to stop a counter which was started by the pulse to the transducer. If any reflections are seen by the receiver, they are after the straight path reception and are therefore ignored. About 8 msec after one transducer has been pulsed, the next one is pulsed to find the distance between that transducer and the receiver. In this way, any number of vector distances from fixed points to the receiver Wand can be determined and thus its position in three-dimensional space can be calculated.

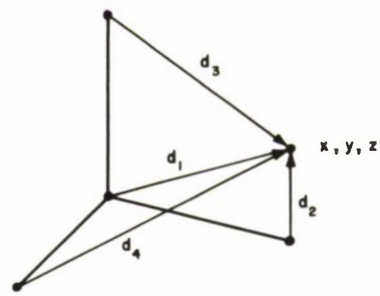
The major inherent advantage of the ultrasonic delay method of determining the position of a stylus is the fact that the measurements are all delay measurements whereby a digital counter provides a direct digital readout without requiring an analog-to-digital conversion. Sound is very convenient for measurement purposes since its propagation velocity is approximately one foot per millisecond. Thus, a 100-kcps counting rate will resolve distance to one-tenth of an inch and a 4-foot delay is only 4 msec. Allowing another 4 msec for reflections to die out, the transducers can be pulsed at 8-msec intervals. Since four transducers are used, the total cycle takes about 32 msec, providing an operating frequency of 30 cps. The TX-2 computer has an internal real-time clock which counts at 100 kcps; therefore, an external counter is not necessary. The start-stop pulses interrupt the computer which then subtracts clock values and measures the time to 10 μsec (0.1 inch). Thus, the measurement of the time delays is accomplished with a minimum of additional hardware or software.

The use of four transmitters instead of three considerably simplifies the calculation of x, y, and z coordinates. If distance measurements are made from two points in space, which differ only in one of the three coordinates (e.g., they lie along an axis), then the calculation of that coordinate is extremely simple. It can be shown that the projection of the Wand onto the axis between the transmitters, i.e., the coordinate position, is proportional to the difference of the squares of two distances. If four transmitters are laid out in space at $(-c,-c,-c)$, $(+c,-c,-c)$, $(-c,+c,-c)$, and $(-c,-c,+c)$, where $c = \frac{1}{4}$, then

$$x = d_1^2 - d_2^2$$

$$y = d_1^2 - d_3^2$$

$$z = d_1^2 - d_4^2 \quad .$$



Thus, it is clear that one reason for using four transmitters is the ease of computing x, y, z. However, a more powerful reason is that a check can be made between the four. If the computed x, y, z are put back into the equation for d_1^2,

$$d_1^2 = (x + c)^2 + (y + c)^2 + (z + c)^2$$

a comparison of the real and computed values of d_1^2 will detect any discrepancy in the measurements. This is very important because one of the direct paths may have been blocked and a reflection received, or perhaps 50-kcps room noise (mainly from typewriters) may trigger the receiver before one of the transmitted pulses arrives. If there are four or more distances measured, a consistency check can be made and the measurement rejected if it is noisy. A simple check of each distance against its previous value is not sufficient, since a reflection appears as a consistently wrong distance as long as the main path is blocked. In fact, the ability to make the consistency check easily has proved even more important than the ease of computing x, y, z, since it is done more often. After initially setting up the transmitters on the TX-2 in the geometry described previously, the decision was recently made to move the transmitters to the corners of a square. The new square geometry will provide a much simplified verification computation at the cost of increased difficulty in the computation of z. The computation of z^2, however, is no harder than the previous check and if it is assumed that the last value of z computed should be fairly close to the new value, it is necessary to perform only one Newton's iteration to produce a new z from z^2. With this simplification, the coordinate computation is less than 100 μsec on the TX-2 or 0.25 percent of the computer's time. The check is about 20 μsec and, if done for every channel, would cost an additional 0.2 percent of the computer's time. These percentage costs might be compared to the cost of light-pen tracking which typically consumes about 5 percent of the computer time, not including search time when the pen is "lost."

The Lincoln Wand has been operational since April 1966. It appears to operate reliably, though the amplifiers and transmitter pulses could be improved considerably to provide better signal-to-noise ratios. The tracking of the Wand is very smooth, partly due to a programmed damping of the x, y, z values which does not adversely affect response speed for normal hand movements. Users tend to move faster than they would normally with a two-dimensional tablet or pen.

The major problem so far seems to be a sensitivity to the noise of typewriters. When a key hits the platten, it produces an impulse which causes noise extending well up into the ultrasonic range. The Wand hears noise only from 40 to 60 kcps but can detect a typewriter halfway across the room. This causes the rejection of some measurements and may even "stop" the Wand tracking in the worst case. It is expected that the transmitter power could be increased, if this proves to be a serious problem.

VI. HARVARD REMOTE TERMINAL

The DEC 338 console to be placed at Harvard is due to be delivered in July and programming is well under way. It will link to the TX-2 and the programs will be designed to accept the standardized network channel code which is currently being worked out. The present plans require the remote computer to maintain the display list, including all the hierarchy information, as well as accept line and conic display data in a general form. The resulting package for the DEC 338, which should make it appear like a normal TX-2 console, appears to require about 4000 words of core storage. This leaves 4000 words for a display file which should be adequate.

VII. COMPUTER NETWORK STUDY

A small computer network will be implemented which will include initially the Lincoln Laboratory TX-2 and the System Development Corporation AN/FSQ-32 and PDP-1 computers located in Santa Monica, California. This implementation should be in operation by Fall 1966. The network will allow experiments to be performed, demonstrations to be given, and user experience to be gathered which should prove valuable in the design of future, larger computer networks.

The data transmission link between TX-2 and SDC will be established over Western Union 4-kcps broadband exchange service dial-up lines, using a Western Union 2121 data set. This equipment will provide a full-duplex, 4-wire link capable of asynchronous data transmission at a rate of 1200 bits per second in both directions concurrently. Initially, the connection will be dialed-up by the computer operator: an automatic calling unit, which will allow the computer to place calls, will be provided at each end as soon as these units are available from Western Union.

At the SDC end, the data set will be connected to one of the PDP-1 teletypewriter channels, suitably modified to operate full-duplex at 1200 bits per second. At the TX-2 end, the data set will feed a terminal unit connected to the low-speed data channel sequence. This I-O sequence, which is now in the detailed design and construction phase, will allow up to 63 low-speed input-output units such as Lincoln Writers, punches, readers, data sets, or similar units to transfer data and commands concurrently on a demand basis with the TX-2. Each low-speed unit will require a suitable terminal unit for connection to this sequence.

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14. KEY WORDS

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